NASA INVENTIONS AND CONTRIBUTIONS BOARD
SPACE ACT AWARD CASE REEVALUATION FORM

NASA Case Number	*Title*	*Date*
ARC–14653-1	FACET: Future ATM* Concepts Evaluation Tool (*ATM = Air Traffic Management)	12 May 2006

Contributor Name	*Employer*	*Percentage of Contribution*
Dr. Banavar Sridhar	NASA	25%
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Mr. Daniel Mulfinger	University of California, Santa Cruz	10%
Dr. Kapil Sheth	University of California, Santa Cruz	20%

Change in Case Status:

Has there been a significant change in the value of this contribution since the last evaluation? Please elaborate by describing the increased significance from a technological, scientific, humanitarian or commercial point of view. Has further development of this contribution occurred? Has usage by NASA, other government agencies or commercial entities increased? Describe any enhancements.

Since the last evaluation in 2004, there have been many significant changes in the status of FACET software development and usage. FACET's significance to the air traffic management community has increased dramatically over the past two years.

To facilitate the review and tracking of significant changes, this NF1329A includes all material from the previous submittals (NF1329 from 2002 and NF1329A from 2004) in black Times font, together with a description of any significant changes from 2004 to 2006 in blue Helvetica font under the appropriate section or sub-section.

The following supporting materials are provided as attachments to NF1329A:

- A list of new FACET-related peer-reviewed publications by contributors, and copies of these papers.
- Letters of endorsement from: FAA, Flight Explorer, Massachusetts Institute of Technology, Metron Aviation, Optimal Synthesis, Inc., Smithsonian National Air And Space Museum, and University of California – Berkeley.
- FACET software documentation (User manual and training materials).
- FACET-based animation of U.S. air traffic data over 24 hours.
- Various FACET-based animations of traffic and/or weather data.

1. DESCRIPTION.

a. Briefly describe the contribution. In addition, if peer-reviewed publications by contributors have been accepted on this topic in refereed journals or for refereed conference papers, please attach a copy with this form as a supplement.

2002: Original write-up

FACET is a flexible software-based simulation environment for exploration, development, and evaluation of advanced Air Traffic Management (ATM) concepts. Examples of concepts studied using FACET are: aircraft self-separation for Free Flight, modeling and prediction of air traffic controller workload, a decision support tool for direct routing, integration of space launch vehicle operations into the U.S. National Airspace System (NAS), and advanced traffic flow management techniques using rerouting, metering and ground delay. FACET models system-wide airspace operations over the contiguous United States. Airspace models (e.g., Center/sector boundaries, airways, locations of navigation aids and airports) are available from databases. Weather models (winds, temperature, bad weather cells, etc.) are also available. FACET models aircraft trajectories using spherical-earth equations; aircraft can be flown along either flight plan routes or direct (great circle) routes as they climb, cruise and descend according to their individual aircraft-type performance models. FACET's modular software is written in the Java and C programming languages and currently has approximately 200,000 lines of code. The architecture of FACET strikes an appropriate balance between flexibility and fidelity. This innovative feature enables FACET to model airspace operations at the U.S. national level, and process over 10,000 aircraft on a single desktop/laptop computer for a variety of operating systems.

NASA-HQ has posted a movie created using FACET, showing 24 hours of air traffic over the U.S. in fast-time, on their website *http://www.hq.nasa.gov/office/aero/facet24.mov*. This movie (provided as an attachment to NF1329) has been used by senior NASA Headquarters officials for briefings on air traffic management. It was also used by Prof. John Hansman of MIT during his briefings to the House Science Committee and the Transportation Subcommittee of the House Appropriations Committee.

2004: Significant Changes from 2002

There are 8 new technical publications (please see attachments for publication list and copies) that augment the FACET-related publications listed for the last evaluation in 2002.

2006: Significant Changes from 2004

There are 12 new technical publications (please see attachments for publication list and copies) that augment the FACET-related publications listed for the prior evaluations.

b. In what NASA program, project or mission has this contribution been used or will be utilized and to what extent? (include any non-aerospace commercialization applications)

2002: Original write-up

FACET has been used to conduct research for NASA's Advanced Air Transportation Technologies (AATT) project, an element of the Aviation System Capacity program. NASA's Virtual Airspace Modeling and Simulation (VAMS) project, a new element of the Aviation System Capacity program, will use FACET for evaluating various system level ATM concepts. FACET supports the "Increase Capacity" objective of the "Revolutionize Aviation" goal under NASA's Aerospace Technology enterprise; the FACET team members received NASA's prestigious Turning Goals into Reality (TGIR) Award in May 2001 for exceptional progress toward this objective. The Advanced Range Technology Working Group, co-chaired by NASA and the U.S. Air Force, is using FACET's modeling capability to develop tools for enhancing range safety during space vehicle launches; this activity supports NASA's Spaceport Technology Development Initiatives, under the "Advance Space Transportation" goal of NASA's Aerospace Technology enterprise.

Technological advances in air traffic management (e.g., methods for modeling uncertainties in air traffic demand, and algorithms for traffic re-routing and system-wide traffic flow optimization) enabled by

FACET can be applied to other large-scale networks such as the internet (data communications), ground transportation systems, and power distribution grids.

2004: Significant Changes from 2002

FACET continues to directly support the Airspace Systems program (formerly Aviation System Capacity program) under NASA's Aeronautics Enterprise, making significant contributions toward the goal of enabling a more efficient air transportation system. For example, FACET's traffic flow initiative assessment capabilities were utilized for a demonstration of NASA's modeling capability by former Ames Director Dr. Harry McDonald, during advocacy of the Virtual Airspace Modeling and Simulation (VAMS) project. The advocacy was successful, and the VAMS project was initiated in 2002 under the Airspace Systems program.

FACET will be utilized to conduct a significant portion of the work performed for 3 new projects initiated in FY04 under the Airspace Systems program:

- Strategic Airspace Usage project
- Efficient Flight Path Management project
- Efficient Aircraft Spacing project

FACET will be integral to all future Airspace Systems program initiatives.

2006: Significant Changes from 2004

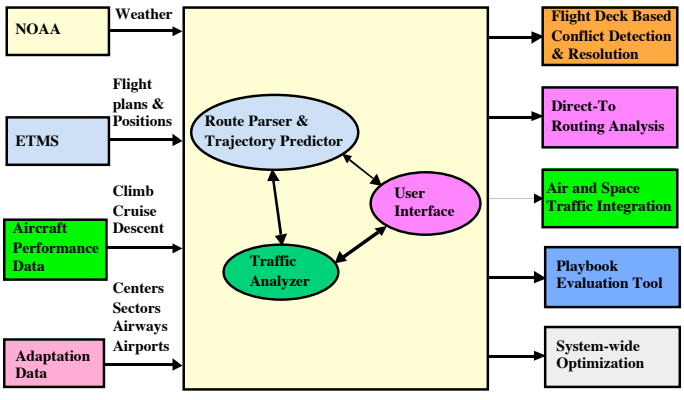
Under NASA's Strategic Airspace Usage (SAU) project, a major initiative was undertaken to mature FACET to a high Technology Readiness Level (TRL), to support operational use by flow specialists at the FAA's Air Traffic Control System Command Center (ATCSCC) and local Air Route Traffic Control Centers (ARTCCs), as well as dispatchers working in Airline Operations Centers (AOCs). FACET's long-term predictions of sector, fix, and airport demand usage were uniquely qualified to support the planning and post-operational assessment of strategic flow management initiatives and airline flight planning operations. As part of this very successful effort, FACET was integrated with numerous FAA tools, such as the Enhanced Traffic Management System (ETMS), the Post Operations Evaluation Tool (POET), and the Jupiter Simulation Environment (JSE). Paralleling this endeavor with the FAA, a significant effort was undertaken to integrate FACET with Flight Explorer in an effort to seamlessly provide FACET capabilities to the diverse airspace user community.

FACET's unique capabilities as a research and development tool continue to support NASA's Airspace System Program by guiding the development of the Next Generation Air Transportation System (NGATS) – Airspace project, in the technical areas of dynamic airspace configuration and system-level traffic flow optimization. FACET will be utilized to conduct a significant portion of the work performed for the NGATS project over the next five years.

c. Provide details describing how the contribution works or operates relative to system, subsystem, components, etc.

2002: Original write-up

FACET consists of four components: 1) algorithms, 2) databases, 3) graphical user interface (GUI), and, 4) applications. The algorithms use data from the databases and process the information needed by the applications, where each application supports one or many ATM concepts (examples provided in Section 1a above). The applications generate decision support data, which are displayed on the GUI. Unique



features include simulation of air traffic over the entire U.S., traffic forecasting, data visualization, and playback of recorded data. For forecasting, FACET uses a real air traffic data feed from the FAA's Enhanced Traffic Management System (ETMS), and weather data provided by the National Oceanic and Atmospheric Administration (NOAA). To provide an environment for both simulation and real-time evaluation of ATM applications, a number of static databases and real-time data sources are utilized. Static databases contain Center/sector boundaries, airways, and locations of navigation aids and airports. Performance models of 66 different aircraft types, with equivalence mapping to over 500 aircraft types, are also stored in a static database. Real-time aircraft position data and flight plan data are obtained from the ETMS traffic data feed, and the wind and temperature data are obtained from the NOAA weather data feed. The data from the static databases and dynamic feeds are used for parsing the flight plan route and constructing four-dimensional trajectories for the climb, cruise and descent phases of flight according to the performance characteristics of the aircraft. These trajectories drive the various ATM applications; for example, these trajectories can be used by the sector count application to determine the peak traffic in the sectors at a future time epoch. FACET also provides extensive two and three dimensional visualization capabilities for display of data generated by various applications. The FACET GUI binds algorithms, databases, applications and visualization tools together. The software, data and visualization components interact with each other via drop-down menus available in the GUI.

2004: Significant Changes from 2002

Over the past two years, there has been a major upgrade of FACET software capabilities, relative to those described in the last evaluation of 2002. Numerous new features and capabilities have been added, while existing capabilities have been refined and/or expanded. Several new studies have been conducted using these capabilities. Major accomplishments are outlined below.

- A recent study conducted by the AATT project office estimated the benefits arising from operational implementation of FACET's traffic flow management capabilities at roughly $200M/year.

- Data Visualization
  - 3-Dimensional display of wind contours as a function of altitude
  - Integration with 4 COTS weather products that are widely used by FAA and airlines
  - Aircraft insertion into overhead traffic stream, for more efficient departure release

- Completed the development of a comprehensive 3-Dimensional Conflict Detection and Resolution capability to model airborne self-separation for mature Free Flight operations.

- FACET has been integrated with a historical database of air traffic. This is a significant development since it provides a benchmark to compare FACET predictions in the presence of uncertainty against historical data under similar conditions.

- Developed a new capability to model Miles-In-Trail (MIT) restrictions, for application to the busy North-East corridor (Washington – Philadelphia – New York – Boston). This is necessary to devise strategies that increase the throughput of this very congested airspace by attenuating/eliminating the effects of MIT restrictions.
  - Demonstrated this capability to the Traffic Management Officers of New York TRACON and New York Center, and to the operators of New York airports (New York Port Authority).
  - Received invitation to present results to the FAA-Airlines Collaborative Decision Making (CDM) community from the FAA CDM chair.

- Evaluated the effect of errors in ETMS data on FACET traffic predictions, and developed several approaches to reduce these errors.

- Integrated "what-if" capability combining different Traffic Flow Management actions: aircraft reroutes based on Playbook, miles-in-trail, and tactical airborne rerouting.

- FACET has been used to develop aggregate models of air traffic flow based on historical data. The aggregate models were then utilized to develop linear time variant system models representing traffic flow in the United States; this permits the analysis and design techniques from Control

System theory to be applied to ATM system design. FACET's ability to model uncertainty, measure the impact of different decision-makers, and its ability to handle the large dynamic ATM system makes it extremely suitable to model and analyze problems in the design of other large complex engineering systems like Electric Power Systems, Information Networks, and Ground Transportation Systems.

2006: Significant Changes from 2004

The main purpose of Traffic Flow Management (TFM) is to address the imbalance between the supply of available airspace and airport capacity and the demand for it placed by the number of arrivals and departures of aircraft during a day. TFM initiatives such as ground stops, ground delay programs, rerouting, airborne holding, and miles-in-trail restrictions, are actions which are needed to control the air traffic demand to mitigate a demand-capacity imbalance. Consequently, TFM initiatives result in National Airspace System (NAS) delays. Of all the causes, weather has been identified as the most important causal factor for NAS delays. Therefore, in order to accurately assess the NAS performance, it has become necessary to create a baseline for NAS performance, and establish a model which characterizes the relationship between weather and NAS delays. A major enhancement in FACET has been the ability to develop and validate models using data about actual delays provided through FAA's Air Traffic Operations Network (OPSNET), traffic described by ETMS traffic data and NOWRAD weather data. It is worth noting that a day of ETMS and NOWRAD data is over 1.5 Gigabytes. The model has been validated using 8 months of data during the thunderstorm weather season from 2004 and 2005. The result of this work provides the FAA with the ability to assess whether the NAS performance envelope is operating in the expected range and look for explanations of anomalous behavior. This development is documented in technical papers.

To support the FAA's Oceanic and Offshore Directorate, a major new initiative has been undertaken within FACET that is designed to optimize the flow of traffic on the structured route system that exists over the Pacific and Atlantic Oceans. The premise behind this new work is that local perturbations in the trajectories of individual aircraft or sequences of aircraft can improve the overall performance of traffic flows in the oceanic domain. These improvements, in turn, can lead to significant fuel savings and an increased ability to accommodate airline routing preferences. The latest developments in this endeavor, which focus on the Central East Pacific (CEP) routes, are documented in a technical paper that will be presented at the 2006 AIAA Guidance, Navigation, and Control Conference.

To support the FAA's new Airspace Flow Program (AFP) that is being implemented this summer to manage traffic during severe weather, FACET was integrated with the FAA's Jupiter Simulation Environment (JSE). This integrated system was used to conduct six human-in-the-loop simulations (HITLs) that were designed to refine the AFP concept in 2005. Participants in these HITLs have included airline dispatchers from all of the major air carriers and FAA Traffic Management Coordinators (TMCs). FACET's role in these simulations has been to visualize and quantify the impact of AFPs on the airlines and airspace.

In addition to the major new initiatives listed above, numerous system level enhancements have been added since 2004 that increase the overall system usability. A list of the most significant new system enhancements follows:

- The post-operations analysis capabilities of FACET have been significantly improved through the addition of a new Single Aircraft Analysis Model (SAAM), a new data plotting facility, and a greatly enhanced aircraft state database query capability. With these new capabilities, aircraft-specific information, such as track histories, flight plan amendments, departure time changes, sector usage statistics, vertical flight profiles, and total travel time/distance statistics can be quickly visualized and analyzed by querying FACET-populated MySQL databases and tables.

- A new "batch processing" mode has been added to FACET that allows the system to be controlled through a scriptable XML interface. This new capability is ideal for processing large quantities of data and testing FACET's performance and stability with benchmark data sets.

- To handle the real-time Aircraft Situation Display to Industry (ASDI) and ETMS data feeds that FACET relies upon, a new data proxy server has been added to handle and isolate all data connectivity, buffering, and archiving activities in the system. This has greatly enhanced the stability of FACET.

- Numerous new FAA data sources, including Aggregate Demand Lists (ADLs), Flow Constrained Area (FCA), OPSNET, Aviation System Performance Metrics (ASPM), and Departure Spacing Program (DSP), have been added to FACET. These new data sources significantly improve the post-operations analysis capabilities of FACET and increase the predictive reliability of the system.

2. SIGNIFICANCE.

a. Explain why the contribution is significant: scientifically, technologically, or from a humanitarian viewpoint, to the aeronautics, space community, and non-aerospace commercial activities.

2002: Original write-up

FACET is scientifically and technologically significant to NASA and other organizations with a need to model, design and operate the large and complex U.S. National Airspace System (NAS). It has two primary uses: (a) as a simulation, modeling and analysis capability at the national level, and, (b) as an environment for the development and evaluation of real-time decision support tools for the FAA and Airlines.

FACET has opened up an entire new area of Air Traffic Management research for NASA. It has been used for: (1) benefits assessment study of a new decision support tool for direct routing, which could result in cost savings of $200M per year for the airlines, (2) feasibility of cockpit-based self-separation for free maneuvering operations (a key element of the Free Flight concept), (3) synthesis of a method for modeling and predicting air traffic controller workload, and, (4) development of traffic flow management technologies for increased NAS throughput and capacity utilization. FACET will play an important role in the evaluation of new ATM operational concepts under NASA's VAMS project by providing the NAS model for several human-in-the-loop simulations. It will also be used to simulate the air traffic environment in the Intelligent Launch and Range Operations Test Bed, a human-in-the-loop simulation environment aimed at improving spaceport operations, as part of the Intelligent Systems project of NASA's Computing, Information and Communication Technology (CICT) program.

Technologies derived from FACET will be used by the FAA's Air Traffic Control Systems Command Center (ATCSCC), Airlines and General Aviation for cooperative decision-making. ATCSCC will be able to use FACET's traffic flow management techniques such as rerouting, metering and ground delay, along with its traffic forecasting ability to develop ATCSCC's daily strategic plan of operations, which will result in efficient traffic flow through the entire NAS. Airlines will use FACET's traffic forecasting abilities to determine airport demand and regions of congestion for planning their fleet operations. Use of FACET-based technologies will improve NAS throughput and utilization, reduce flight delays and/or cancellations, and provide common situational awareness. Better utilization of existing resources will allow the existing NAS infrastructure to accommodate growth of air traffic for several years. Reduction of delays and better schedule adherence will improve airline profitability, which will directly benefit the U.S. economy. The airline passengers will also experience a higher degree of satisfaction due to fewer delays and cancellations.

b. Estimate the degree of scientific or technological significance by a mark on the line below:

0	1	2	3	4	5
				X	
None	***Modest***	***Average***	***Major***	***Maximum***	

c. Estimate the significance of the contribution relative to a specific NASA program or mission by marking the line below:

0_____1_____2_____3_____4__X__5

None ***Modest*** ***Average*** ***Major*** ***Critical***

3. STAGE OF DEVELOPMENT.

Indicate the stage of development of the contribution by a mark on the line below:

0_____1_____2_____3_____4__X__5

Concept ***Simulated*** ***Tested*** ***Fully Developed*** ***Operational***

4. ASSESSMENT OF USE.

a. If the contribution is now in operation, describe its performance and value within both the aerospace field and its application to non-aerospace commercial and government uses.

2002: Original write-up

FACET has been in operation for about 3 years. It has been used by NASA-Ames researchers to conduct research for NASA's AATT and VAMS projects. Ames researchers in the Human Centered Computing Group are using the software to provide realistic nation-wide traffic data to pilots through a cockpit display technology in a human-in-the-loop-simulation capability.

The FAA's 2002 Enroute Work Group, with a mission to identify technology and procedures to improve traffic flow during disruptive weather months, has recommended rapid prototyping of a FACET-derived flight scheduling tool for airline operations centers. FACET is currently being evaluated by the Airline Dispatchers Federation (ADF) for use by the dispatch profession. It has also been extensively used by the industry for various ATM applications. FACET's air traffic models and analysis tools are an emerging standard for system-level ATM analysis.

The FACET software has been released (under a Non Disclosure Agreement) to 20 external organizations (outside NASA-Ames) in the government, industry and universities, as described below.

Volpe National Transportation Center: In collaboration with NASA-Ames, the U.S. Dept. of Transportation's Volpe Center is using FACET to develop algorithms to evaluate planning and execution of various traffic flow management initiatives at the national and regional level.

FAA Commercial Space Technologies Office: Uses the software to study new algorithms to provide procedural guidelines for interaction between space vehicles and air traffic.

FAA Free Flight Program Office: Using the software to evaluate new concepts for the FAA's Operations Evolution Plan.

FAA Technical Center: Using the software to support their analysis capabilities for evaluating human factors issues.

NASA Langley Research Center: Used the software to simulate air traffic data in the NAS to study the feasibility of futuristic concepts.

Boeing: Evaluation of software for the design of future NAS Flow Management System.

Charles River Analytics, Inc.: Developed agent-based models within FACET for advanced air traffic management studies. The software was used to develop a realistic distributed air/ground traffic management scenario involving a group of mixed equipage aircraft and to develop negotiation strategies between controller, airline, and pilot agents.

Command and Control Technologies Corporation: Used the software to develop a virtual spaceport simulation facility suitable for experimenting with novel human-centered computing techniques to improve space launch, payload and mission operations. FACET enabled them to establish a framework for collaborative research, which includes current space flight programs at NASA Kennedy Space Center, academia, and industry.

Computer Sciences Corporation: Using the software to study its interoperability with other Decision Support Tools, e.g. Departure Sequence Program, to optimize operations at airports.

Intelligent Automation, Inc.: Used the software to investigate distributed air traffic control as it applies to ATM, and to evaluate mathematical concepts in Chaos theory as applied to ATM.

Logistics Management Institute: Evaluating the software for use in analyzing new concepts in Air Traffic Control.

Massachusetts Institute of Technology: Used FACET to analyze air traffic and develop new Conflict Detection and Resolution algorithms.

Metron, Inc.: Used the software to analyze accuracy of sector congestion prediction and quantification of various error sources. They evaluated the potential for operational benefit through deployment of FACET capabilities. They are assessing further development and integration of FACET capabilities with other TFM tools.

Micro Analysis & Design: Used FACET's air traffic simulation capability to support a human performance simulation of en route controller roles and responsibilities for inter-sector planning.

MIT Lincoln Labs: Used the software for analysis and simulation capability of rerouting air traffic around bad weather regions.

Northwest Airlines: Investigating FACET software for rapid prototyping into an Airline Operations Center (AOC) based pre-emptive Traffic Flow Management (TFM) tool. The software will be used as an enroute congestion management tool with sufficient capability to model TFM alternatives before they occur, and to evaluate their impact on the National Airspace System (NAS). FACET is being evaluated to provide an open environment for collaborative input of participant data and optimization of NAS resources.

Optimal Synthesis, Inc.: Used FACET to develop a software environment for ATM algorithm development. They are modifying FACET to provide analysis software for the licensing and regulation of commercially operated launch sites. They also evaluated mathematical concepts of stability and robustness of distributed ATM systems.

Seagull, Inc.: Using the software to develop gate-to-gate modeling capability as part of the Aviation Systems Capacity program's Virtual Airspace Modeling and Simulation (VAMS) project.

State University of New York at Stony Brook: Used the software to evaluate concepts of obstacle avoidance as applicable to constrained traffic situations.

University of California at Berkeley: Using the software to develop advanced traffic flow optimization methods.

2004: Significant Changes from 2002

Several new organizations have been added to the growing list of FACET users:

- American Airlines
- BLR Group. Inc.
- Draper Laboratory
- Northrop Grumman
- Ohio State University

- Southwest Airlines
- Titan Corporation.

2006: Significant Changes from 2004

Several new organizations have been added to the growing list of FACET users:

- Aviation Management Associates, Inc.
- FAA Air Traffic Control System Command Center
- FAA New York TRACON
- Cambridge Aviation Research
- CNA Corporation
- CSSI
- General Dynamics
- Imperial College, London (UK)
- NORAD/USAF
- Sensis
- Stanford University
- University of Cincinnati
- University of Maryland
- US Airways
- Washington State University

b. If the contribution is not now in operational use, describe its most likely or previous applications and the extent of commercial, (includes non-aerospace commercialization) government and/or NASA-specific uses.

2002: Original write-up

As described in the previous subsection, FACET simulation and modeling capability has been in operation for the last three years and has been extensively used for different applications by NASA, FAA, Industry and universities. A FACET-derived real-time decision support tool for operational use by the airlines and FAA is under development.

c. Will the contribution increase in value or in its applications over time and in what manner?

It is fully expected that FACET development will continue over the next several years, significantly increasing its value and applications over time. It will continue to be used by NASA and the FAA for the development and evaluation of novel concepts. Mature FACET technologies will continue to be transitioned into operational tools for traffic flow management. Universities will use FACET to teach students air traffic control (ATC) and to conduct advanced ATC research. Small-business users of FACET will explore innovative concepts to advance the state-of-the-art. The industry users will utilize FACET to develop, evaluate and validate their tools in a realistic ATC environment, which will lead to commercial products for the cockpit and for air traffic service providers. Airline use of FACET will result in improved flight planning decisions in the presence of traffic flow constraints, which will lead to reduction of delays and cancellations, and improvement of fleet operations.

Interest in FACET has been growing at a rapid rate, as evidenced by an increasing number of requests for the software from external organizations that believe FACET is a valuable tool for their work in various aspects of air traffic management. The number of potential users is therefore expected to grow dramatically, with an estimate of around 100 users over the next few years.

2004: Significant Changes from 2002

Technology Transfer to Government and Industry

- NASA has developed a real-time version of FACET that directly interfaces with the FAA's Enhanced Traffic Management System (ETMS). ETMS currently provides traffic visualization and planning capabilities on Traffic Situation Displays for roughly 500 airspace users at over 100

operational sites across the nation. FACET's reroute conformance monitoring function will provide the FAA with a unique capability to monitor user conformance with nationally implemented rerouting initiatives. This functionality will be deployed by the FAA in the next release of ETMS (version 7.9), scheduled for October 2004.

- Computer Sciences Corp. (CSC), funded by NASA's Strategic Airspace Usage project, is working to integrate FACET with the FAA's Departure Spacing Program (DSP). Preliminary analysis indicates that FACET-DSP integration improves load balancing of an airport's departure traffic pattern. CSC staff is coordinating with FAA personnel at the Air Traffic Control System Command Center to customize FACET capabilities for future operational adoption.

- FACET software has been installed at the U.S. Department of Transportation's Volpe Center and Northwest Airlines' operations center; it has been running with live national traffic data at both locations. FACET software at Northwest Airlines has been integrated with the Corridor Integrated Weather System and the combination provides airline dispatchers, for the first time, an integrated display of both traffic and weather.

- Metron Aviation is working with NASA personnel to utilize FACET for the FAA's Jupiter simulation project, whose goal is to provide en route modeling and situation awareness capability (displays) for human-in-the-loop simulations. These simulations will evaluate new concepts for Collaborative Decision-Making between airlines and FAA to increase system throughput and reduce delays.

- FACET is being integrated with Metron Aviation's Collaborative Routing Resource Allocation Tool (CRRAT), under a Phase 2 SBIR contract. This integration will enable airlines to make better decisions on flight substitutions and cancellations to more efficiently use the limited slots allocated by the FAA during Ground Delay Programs.

- FACET is being integrated with Metron Aviation's Post Operations Evaluation Tool (POET), under a Phase 2 SBIR contract. POET is a powerful data mining and visualization tool that provides the FAA and airlines with detailed analysis capabilities of air traffic operations. The FACET-POET integration will help identify areas of congestion and inefficiency in the National Airspace System (NAS), and design/evaluate flow management strategies to address these problems.

- The FAA Free Flight Program Office (Washington, D.C.) hosted a FACET User Group Workshop in March 2003. Participants included representatives from NASA, FAA, industry, and universities.

- Several one/two-day FACET user training sessions have been held for FAA, airline, university, and industry personnel, tailored to their scope of use. To date, over 50 users have been trained on applications of FACET. The following training/experiment sessions for FACET users are scheduled for 2004:

  April 12–14: Northwest Airlines
  June: Southwest Airlines
  August: UPS
  May: Flight Explorer
  July: Metron Aviation, Inc.
  September: University of California, Berkeley

2006: Significant Changes from 2004

Technology Transfer to Government and Industry

- In June 2005, a FACET-derived technology, called Reroute Monitor, was implemented in version 8.0 of the FAA's Enhanced Traffic Management System for operational use at over 100 FAA field sites.

- The FAA's Airspace Flow Program (AFP), scheduled for implementation in summer 2006 at over 100 FAA facilities, utilized FACET for concept development and prototyping. AFP will substantially reduce travel delays, potentially saving airlines millions of dollars each year.

- The Smithsonian Institution's National Air and Space Museum is incorporating key features of FACET into a new exhibit, called America by Air, scheduled to open in 2007. The museum's annual attendance is estimated at 9 million visitors from all over the world.

- To better support FACET's growing user community, the FACET training curriculum has been completely overhauled since 2004. The new curriculum consists of a two-day self-paced or on-site training program. Included in this curriculum are sessions on current and future applications, data sources and formats, interactive demonstrations and problem solving sessions. Examples of the guide training and problem solving session course material are provided as part of this SOYA application package. Recent training sessions include:

  - May 11-12, 2006 for FAA ATCSCC and Traffic Management Coordinators (TMCs) from select ARTCCs; conducted at the ATCSCC facility in Herndon, VA.
  - Jan. 18-19, 2006 for FAA ATO-E (Oceanic and Offshore Directorate) and CSSI, Inc.
  - Sept. 27-29, 2005 for the FAA Air Traffic Control System Command Center (ATCSCC), Metron Aviation Inc., and Flatirons Solutions

5. CREATIVITY.

What is your assessment of the creativity displayed in the conduct of this contribution, relative to the expected performance of those in similar positions?

*None*_____*Low*_____*Modest*_____*Average*_____*High*_____*VeryHigh*_____**X**___

2002: Original write-up

FACET software successfully blends two programming languages: Java for the graphical user interface (GUI) and C for the underlying computational engine. This innovative feature enables the portability of FACET over a wide range of computers running on a variety of operating systems. The architecture of FACET was designed for an appropriate balance between flexibility and fidelity, enabling it to model airspace operations at the U.S. national level, and process over 10,000 aircraft on a single desktop or laptop computer.

6. RECOGNITION

What forms of recognition have been received by the contributors for this contribution? Have previous awards been made to the contributor(s) for this accomplishment? Please describe.

2002: Original write-up

NASA Turning Goals into Reality (TGIR) 2001 Award: For exceptional progress towards the "Increase Capacity" objective of the "Revolutionize Aviation" goal under NASA's Aerospace Technology enterprise. This award was presented to the Future ATM Concepts Evaluation Tool (FACET) Team on May 16, 2001. The team members were Dr. Banavar Sridhar, Dr. Gano B. Chatterji, Dr. Kapil Sheth, Dr. Shon Grabbe and Dr. Karl Bilimoria.

2001 Raytheon Excellence in Technology Award: Presented to Dr. Kapil Sheth, Dr. Gano Chatterji and Daniel Mulfinger. The Raytheon Award for Excellence in Technology program is the prestigious enterprise-wide award program established to provide visible recognition and reward for technical achievement among key contributors, both individuals and teams. An executive selection team reviewed the candidates and selected those to be honored with the Distinguished Level award. FACET is one of nine individuals and fifteen teams that were selected to receive Distinguished Level awards, and personally honored by the CEO of Raytheon, Dan Burnham.

2001 Raytheon ITSS Science and Technology Award: For scientific and technical achievement by the FACET group. This award honors an individual or team selected from Raytheon ITSS projects performed during the previous year. This award was established to honor men and women who enhance Raytheon customers' success through their superb performance and technological expertise. FACET team members honored were Dr. Kapil Sheth, Dr. Gano Chatterji and Daniel Mulfinger.

2001 Raytheon Peer Award: Dr. Gano Chatterji received the award for his expertise in air traffic management, the development of the FACET data framework, as well as its aircraft performance modeling and trajectory synthesis techniques. From dozens of nominations by fellow employees, a committee composed of the previous year's winners chose eight individuals.

Ames Contractor Council's 2001 Contractor Excellence Award: To Dr. Kapil Sheth for not only being responsible for assembling the Raytheon team that developed FACET, but also for helping to formulate the original concept and playing a major role in its software implementation.

1999 Raytheon Team Award: Presented to Dr. Kapil Sheth, Dr. Gano Chatterji and Dr. Shon Grabbe for FACET development.

2006: Significant Changes from 2002

2003 Space Act Board Software Release Award: Presented to Dr. Banavar Sridhar, Dr. Karl Bilimoria, Dr. Shon Grabbe, Dr. Kapil Sheth, Dr. Gano Chatterji, and Mr. Daniel Mulfinger. This certificate was presented "for the creative development of technically significant software which has been accepted and approved for dissemination to the public by NASA, entitled FACET."

2004 NASA Headquarters Certificate of Recognition: Presented to Dr. Banavar Sridhar, Dr. Karl Bilimoria, Dr. Shon Grabbe, Dr. Kapil Sheth, Dr. Gano Chatterji, and Mr. Daniel Mulfinger. This certificate was presented for "the creative development of exceptional scientific and technical contributions which have been determined to be of significant value in the advancement of the aerospace technology program of NASA, entitled: FACET Future Air Traffic Management Concepts Evaluation Tool."

2005 NASA Certificate of Recognition: Presented to Dr. Banavar Sridhar, Dr. Karl Bilimoria, Dr. Shon Grabbe, Dr. Kapil Sheth, Dr. Gano Chatterji, and Mr. Daniel Mulfinger. This certificate was presented for the FACET team's "invention, which has been filed by NASA for a patent with the U.S. Patent and Trademark Office."

2005 Ames Honor Award: Presented to Dr. Banavar Sridhar, Dr. Karl Bilimoria, Dr. Shon Grabbe, Dr. Kapil Sheth, Dr. Gano Chatterji, and Mr. Daniel Mulfinger. This award was presented to the FACET team "for excellence in the category of commercialization/tech transfer".

7. TANGIBLE VALUE.

As a measure of the tangible value of this contribution, estimate the following:

a. NASA cost savings to date and in future years.*

**State the rationale for the above cost estimates.*

2002: Original write-up

FACET's development has been driven by research needs and project budgets. It was originally developed under NASA's AATT project to model and predict air traffic controller workload, and to investigate the feasibility of cockpit-based traffic separation methods. Hence, the initial software development was driven primarily by the research needs of these two topics. Over a period of time, additional tools and applications were added, as necessary, to FACET's core capability for the study of other ATM issues such as Direct-To routing, integration of launch-vehicle operations with air traffic operations, and evaluation of traffic management initiatives for cooperative decision making. The FACET development approach – to gradually build and expand functionality as needed while meeting the requirements and schedule of a focused program – has produced a versatile ATM tool at a very low cost. FACET development costs are estimated at $2.5M (cumulative total over the past 5 years); this estimate is based on roughly 20 in-house person years at $125K per person year. It is estimated that it

would have taken an outside contractor a total of $5M (25 person years at $200K per person year) to develop an equivalent capability. This represents a cost savings to NASA of roughly $2.5M to date.

FACET plays a key role in NASA's recently initiated VAMS project. Over the next 5 years, VAMS will use FACET for high level gate-to-gate modeling and simulation development, as well as analysis and human-in-the-loop evaluation of novel ATM concepts. It is estimated that it would now cost around $8M for an outside contractor to develop an ATM tool comparable to FACET (as it exists today), and it would take about 2 years to complete this task. Since FACET is already operational and available for use, this represents a future cost savings to NASA of around $10M; the estimate is based on the $8M cost of the software contract and the impact of a 2-year delay ($1M per year) to the VAMS project.

b. Current market value and potential as a commercial product or process.

2002: Original write-up

FACET's overall commercialization potential is believed to be significant. It can be marketed to industry engineers and university students as an ATM system modeling, analysis and evaluation tool. Estimating a customer base of 250 users, and a per-copy price of $40K, results in a potential market value of $10M.

A FACET-derived real-time decision support tool can be marketed to the airlines and the FAA. Estimating a customer base of 50 users worldwide, and a per-copy price of $500K, results in a potential market value of $25M. This estimate is based partly on the current $1M per-copy price of the ATM simulation tool known as Total Airspace and Airport Modeler (TAAM).

2004: Significant Changes from 2002

NASA Intellectual Property Status

A patent application for FACET has been prepared in collaboration with the NASA-Ames Office of the Chief Counsel. It is anticipated that this application will be filed with the U.S. Patent Office in June 2004.

2006: Significant Changes from 2004

A patent application was filed in 2004, and is currently being processed.

2004: Significant Changes from 2002

Commercialization Partnerships with Industry

(1) A Nonreimbursable Space Act Agreement between NASA-Ames and Flight Explorer (FE) has been prepared by the Ames Commercial Technology Office; the draft agreement has received the concurrence of FE, and final NASA approval is imminent.

Flight Explorer is the world's leading provider of internet-based real time flight tracking and information systems, reporting, and display products. Their principal product is Flight Explorer Professional 4.2, an aircraft situation display (ASD). Flight Explorer has clients worldwide, but the majority are in the United States. Flight Explorer customers include: 80% of major U.S. airlines; 22 of the top 30 regional airlines; all of the top 5 express carriers; 9 of the top 10 executive jet operators; plus hundreds of air charters, corporate flying departments, airports, and U.S. government agencies including the FAA, DoD, and the National Weather Service.

Flight Explorer has applied for a nonexclusive worldwide license with intent to market and bundle basic FACET functionalities with Flight Explorer Professional ASD for low-end users, and the full FACET software as an option for high-end users of its Flight Explorer Professional ASD. This marketing will be aimed at Flight Explorer's entire customer base, which currently has roughly 4,700 licences.

2006: Significant Changes from 2004

A Space Act Agreement between NASA and Flight Explorer (FE) was signed in 2005. Flight Explorer is the world's leading provider of internet-based real time flight tracking and information systems, reporting, and display products, with a customer base of approximately 4,700 licenses. NASA has granted Flight Explorer a nonexclusive worldwide license to market key FACET functionalities bundled with their new product FE6.0, released in Feb 2006.

(2) Under a Phase 1 SBIR contract, Optimal Synthesis Inc. is developing a software interface between FACET and MATLAB® to enable rapid prototyping of next-generation air traffic management algorithms. MATLAB® integrates mathematical computing, visualization, and a powerful language to provide a flexible environment for technical computing; it has become an industry-standard platform for engineers to share and exchange algorithms. This activity is very significant because it can provide commercial access to FACET for the entire MATLAB® users community, which numbers in the thousands.

2006: Significant Changes from 2004

Optimal Synthesis, Inc. is now working under a Phase 2 SBIR contract to develop a scriptable, Java-based interface that will allow MATLAB® and Jython users to modify and operate FACET either locally or remotely from either of these widely-used environments. This version of FACET has excellent commercialization potential among air traffic control enthusiasts in the 500,000+ MATLAB® and Jython user community.

c. Other measurable value: increased efficiency, enabling technology, improved management, etc.

2002: Original write-up

FACET has provided a common base for development and testing of concepts and algorithms developed under research contract Task Orders and university grants supported by the AATT program, as well as Phase 1 and 2 contracts under the Small Business Innovation Research (SBIR) program. The common-base approach has resulted in the integration of tools built by both in-house and outside contributors into FACET. This has led to more efficient software development by avoiding duplication of efforts and facilitating the re-use of algorithms and software.

FACET has also been used to help make key investment decisions: (1) The FAA is considering the deployment of a new controller decision support tool for direct routing, known as D2, under its Free Flight Phase 2 program; a benefits assessment conducted using FACET indicated that national deployment of the D2 tool could result in cost savings of $200M per year. (2) FACET software was used to demonstrate NASA's capabilities in ATM system modeling, visualization and analysis to the NASA Associate Administrator for Aerospace Technology, providing valuable input to the decision-making process for NASA's investment in the recently established VAMS project.

Airlines' use of FACET for flight planning will result in significant cost savings due to reduced delays and cancellations. According to industry estimates, the annual cost of delays in 1999 was over $3B, corresponding to nearly 40% of the net profit of all U.S. airlines (roughly $8B). Recovering even a small part of that cost by using FACET to reduce delays would have a significant positive impact on the profitability of U.S. airlines. Use of FACET by the FAA for training and airspace redesign purposes will result in the formulation of new procedures for improving safety and efficiency. Improved ATC operations will enable the safe growth of air traffic operations, providing significant benefits to the U.S. economy.

Primary Evaluator

Printed Name and Signature	Title	Comments	Date
Dr. Jeffery Schroeder	Chief (Acting), Aviation Systems Division	FACET represents a significant breakthrough in simulation capability for visualization and analysis of air traffic management concepts and procedures. It is rapidly becoming a standard within industry, government, and the university community for this type of analysis. The airlines have identified significant value in using this software to assist their dispatch personnel in rerouting flights as a result of disturbances in the NAS. FACET is a new and innovative software achievement for which NASA can be very proud.	4/19/06

NASA Technical Management

Printed Name and Signature	Title	Comments	Date
Dr. Thomas A. Edwards FOR	Director of Aeronautics	I strongly support the FACET team for the "Software of the Year Award." FACET has proven to be a robust and flexible ATM modeling, simulation and analysis tool for use by government, universities, and industry. It has been used by the Airspace Systems Program to make technical trade-offs and investment decisions. There is strong FAA and airline support for the ongoing development of a FACET-derived decision support tool to improve traffic flow planning.	4/14/06

Awards Liaison Officer

Printed Name and Signature	Title	Comments	Date

NASA FORM 1329A Apr 03